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Circular No. 15.

UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF FORESTRY.

SUMMARY OF MECHANICAL TESTS ON THIRTY-TWO SPECIES OF AMERICAN WOODS.

GENERAL REMARKS.

The following statement of results of the timber investigations carried on by the Division of Forestry, comprising a condensed summary of all the mechanical tests performed in the laboratory at St. Louis under Prof. J. B. Johnson, is published in advance of more detailed discussion of the same, in order to give account of the amount of work performed, to exhibit the necessity for further work on most of the species investigated, and to place as quickly as possible the results within reach of the wood consumers *for what they are worth at this unfinished stage of the investigation.*

For those unacquainted with previous publications of this timber-physics series, it may be stated that the object of these investigations is by no means only the establishment of reliable strength values, although this object is attained simultaneously, but to increase in general the knowledge of the properties and behavior of wood, to find out the differences, if any, of material grown under different conditions, and especially to discover such facts as may lead to the formulation of rules of inspection which will enable the consumer to judge of the comparative value of a given stick and to select and treat more carefully the material for different uses.

Before such results can be attained, a great deal of detail study of the tests and test material will be necessary, supplemented by additional series of special tests, for which so far the facilities have been lacking.

The chief points of superiority of the data obtained in these investigations lie in: (1) Correct identification of the material, it being collected by a competent botanist in the woods; (2) selection of representative trees with record of age, development, place and soil where grown, etc.; (3) determination of moisture conditions and specific gravity and record of position in the tree of the test pieces; (4) large number of trees and of test pieces from each tree; (5) employment of large and small sized test material from the same trees; (6) uniformity of method for an unusually large number of tests.

The entire work of the mechanical test series, carried on through nearly six years intermittently as funds were available, comprises so far 32 species, with 308 test trees, furnishing over 6,000 test pieces, supplying material for 45,336 tests in all, of which 16,767 were moisture and specific gravity determinations on the test material.

In addition to the material for mechanical tests, about 20,000 pieces have been collected from 780 trees (including the 308 trees used in mechanical tests) for physical examination to determine structure, character of growth, specific gravity of green and dry wood, shrinkage, moisture conditions, and other properties and behavior.

In addition to the regular series of tests, the results of which are recorded in the subjoined tables, special series to determine certain questions were planned and carried out in part or to finish, adding 4,325 tests to the above number.

TABLE I.—*Account of test material.*

No.	Name of species.	Number of trees.	Number of mechanical tests.	Average specific gravity of dry wood.	Localities and number of trees from each.
1	Longleaf Pine (Pinus palustris.)	68	6,478	0.61	Alabama, coast plain (22) *a*; uplands (6); hill district (6); Georgia, undulating uplands (6); South Carolina, coast plain (7); Mississippi, low coast plain (2); Louisiana, low coast plain, gravelly soil (7); sandy loam (6); Texas, low coast plain (6).
2	Cuban Pine (Pinus heterophylla.)	12	2,113	.63	Alabama, coast plain (6); Georgia, uplands (1); South Carolina, coast (5).
3	Shortleaf Pine (Pinus echinata.)	22	1,831	.51	Alabama, uplands (4); Missouri, low hilly uplands (6); Arkansas, low hilly uplands (6); Texas, uplands (6).
4	Loblolly Pine (Pinus tæda.)	32	3,335	.53	Alabama, mountainous plateau (8); low coast plain (6); Arkansas, level flood plain (5); Georgia, level coast plain (6); South Carolina, low coast plain (7).
5	White Pine (Pinus strobus.)	17	540	.38	Wisconsin, clay uplands (5); sandy soils (4); sandy loam (5); Michigan, level drift lands (3).
6	Red Pine (Pinus resinosa.)	8	412	.50	Wisconsin, drift (5); Michigan (3).
7	Spruce Pine (Pinus glabra.)	4	696	.44	Alabama, low coast plain.
8	Bald cypress (Taxodium distichum.)	20	3,396	.46	South Carolina, pine barren (6); river bottom (4); Louisiana, coast plain, border of lake (4); Mississippi, Yazoo bottom (3); upland (3).
9	White Cedar (Chamæcyparis thyoides.)	4	354	.37	Mississippi, low plain.
10	Douglas Spruce (Pseudotsuga taxifolia.)	.....	225	.51	(From lumber yard.)
11	White Oak (Quercus alba.)	12	1,009	.80	Alabama, ridges of Tennessee Valley (5); Mississippi, low plain (7).
12	Overcup Oak (Quercus lyrata.)	10	911	.74	Mississipi, low plain (7); Arkansas, Mississippi bottoms (3).
13	Post Oak (Quercus minor.)	8	256	.80	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3).
14	Cow Oak (Quercus michauxii.)	11	935	.74	Alabama, Tennessee Valley (4); Arkansas, Mississippi bottoms (3); Mississippi, low plain (4).
15	Red Oak (Quercus rubra.)	7	299	.73	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (2). *b*
16	Texan Oak (Quercus texana.)	3	479	.73	Arkansas, Mississippi bottom.
17	Yellow Oak (Quercus velutina.)	5	222	.72	Alabama, Tennessee Valley (5).
18	Water Oak (Quercus nigra.)	4	132	.73	Mississippi, low plain (4).
19	Willow Oak (Quercus phellos.)	12	649	.72	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3); Mississippi low plain (4).
20	Spanish Oak (Quercus digitata.)	11	1,035	.73	Alabama, Tennessee Valley (5); Arkansas, Mississippi bottom (3); Mississippi, low plain (3).
21	Shagbark Hickory (Hicoria ovata.)	6	794	.81	Mississippi, alluvial plain (3); limestone (3).
22	Mockernut Hickory (Hicoria alba.)	4	300	.85	Mississippi, low plain.
23	Water Hickory (Hicoria aquatica.)	2	197	.73	Do.
24	Bitternut Hickory (Hicoria minima.)	4	100	.77	Do.
25	Nutmeg Hickory (Hicoria myristicæformis.)	3	294	.78	Do.
26	Pecan Hickory (Hicoria pecan.)	2	172	.78	Do.
27	Pignut Hickory (Hicoria glabra.)	3	84	.89	Do.
28	White Elm (Ulmus americana.)	2	91	.54	Mississippi, bottom.
29	Cedar Elm (Ulmus crassifolia.)	3	201	.74	Arkansas, bottom.
30	White Ash (Fraxinus americana.)	3	476	.62	Mississippi, bottom.
31	Green Ash (Fraxinus lanceolata.)	1	45	.62	Do.
32	Sweet Gum (Liquidambar styraciflua.)	7	508	.59	Arkansas, bottom (3); Mississippi. low plain (4).

a Sixteen of these were bled trees to study the effects of boxing.
b These two should probably be classed as Southern Red Oak. They were collected before the distinction was finally decided upon.
NOTE.—The values for specific gravity here given refer to "dry" wood of test material, i. e., wood containing variable amounts of moisture below 15 per cent; the moisture effect has therefore not been taken into account, but more careful experiments indicate that its influence on specific gravity at such low per cent is so small that it may be neglected for practical purposes.

The special series on which work was undertaken were the following:

1. Effect of bleeding Longleaf Pine, involving 1,300 mechanical tests on bled timber, the material being taken from two sites, namely, one where the timber had been bled and abandoned 5 years, the other where it had been bled and just abandoned. For comparison the tests of the regular series were used. In addition, 300 chemical analyses were made on wood of bled and unbled timber. A complete demonstration of the absence of effect on the strength of the material resulted as recorded in Bulletin 8.

2. Influence of size in beams on the strength, involving 698 tests, namely, 310 tests of large beams (188 of conifers, 122 of hardwoods) and 388 tests of small sticks cut from 78 of these large beams. Of these, 65 tests were specially devised so that small sticks cut from 5 large beams were cut before and after testing the latter, sticks being cut from near the point of rupture and from the ends, sticks from compression side and tension side having been kept separate. Results indicate that no injury is done by the test to the parts away from visibly injured portions and that large beams may be as strong as the small sticks cut from them.

3. Influence of size in compression members, involving 111 tests on large columns (77 of conifers, 34 of hardwoods) and 238 tests on pieces cut from uninjured parts of the columns after testing these. Results indicate that columns may be as strong as small compression pieces, and when weaker the presence of internal defects probably accounts for the differences.

4. Variation of strength and of effect of moisture, across section, and with height of tree, effect of age of tree on the character of this variation, and various allied questions, involving 540 mechanical tests and 270 moisture determinations on quarter-sawed material. Results of this series have not been sufficiently studied to allow of conclusions.

5. To determine more exactly the relation of moisture to strength, a series of tests on smaller pieces of 14 species was instituted, involving 1,866 mechanical tests (on 2 by 2 by 30 inch pieces from 6-foot logs) and 933 moisture determinations. The results obtained on the general series of 4 by 4 inch sticks were fully confirmed, the difference in strength between green and dry wood appearing if anything even greater for the small sizes.

6. To obtain indications of the probable difference of distribution of moisture throughout green and dry sticks, 65 moisture determinations on White Oak and 61 on White Pine were made, using sticks cut from the same scantling for both the green and dry state and making the determinations each time on two adjoining sections of the same stick, one of one-eighth inch, the other of three-eighths inch, from one end to the other of the stick. The results indicate that in sticks in which moisture is evenly distributed when green it is by no means always evenly distributed throughout the stick while seasoning. It also appeared that moisture determinations from contiguous (one larger, one smaller) sections by the method employed (weighing entire sections before and after drying) vary sufficiently to account for errors amounting to several per cent.

7. Partly to study effects of moisture and partly to obtain data as to the behavior of wood after seasoning, a series of tests were made to find if any difference in strength existed between wood which was drying and that which was reabsorbing moisture after leaving the dry kiln, when both were of the same per cent of moisture. This series involved 224 mechanical tests and 224 special moisture determinations and weighings. The results seem to indicate that no material difference in strength exists, so that it would be immaterial whether a given moisture condition was acquired by drying or by reabsorption after having been fully seasoned.

8. To ascertain the effect of hot-air treatment in dry kilns, involving 200 mechanical tests and 40 moisture and specific gravity determinations. The results indicate no detrimental effect, contrary to common opinion.

9. To investigate the claims of certain processes which apply high temperature and high pressure to increase durability and strength of wood, involving 210 mechanical tests and 42 each of moisture and specific gravity determinations, besides 32 chemical analyses.

Results would appear to refute the claims as to effective chemical changes, and as to strength the effect seems to be either negative or injurious.

10. To ascertain whether immersion affects strength beyond the simple moisture effect, 65 mechanical tests on soaked and unsoaked material from the same scantlings were made. The results as far as they go clearly disprove the prevalent notion, the material remaining practically unaffected by immersion even of six months' duration.

Most of these series must be considered as simply preliminary, furnishing indications rather than demonstrations, for which latter more carefully devised and executed series of laboratory experiments are necessary.

Adding to the number of tests of the ordinary series, they at the same time formed a check on the methods employed in that series, and thus were of additional value.

As will be observed, some species, notably the Southern pines, have been more fully investigated, and the results on these (which have been published more in detail in Circular No. 12) may be taken as authoritative. With those species, of which only a small number of trees have been tested, this can be claimed only within limits and in proportion to the number of tests.

The great variation in strength which is noticeable in timber of the same species makes it necessary to accept with caution the result of a limited number of tests as representing the average for the species, for it may have happened that only all superior or all inferior material has been used in the tests. Hence we would not be entitled to conclude, for instance, that Pignut Hickory is 14 per cent stronger than Shagbark, as it would appear in the table, for the 30 test pieces of the former may easily have been superior material. Only a detailed examination of the test pieces or a fuller series of tests would enlighten us as to the comparative value of the results.

The following data, therefore, are *not* to be considered as in any sense final values for the species except where the number of trees and tests is very large:

TABLE II.—*Results of tests in compression endwise.*

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average highest 10 per cent of tests.	Average lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*
1	Longleaf Pine	1,230	11,900	3,400	8,600	5,700	6,900	53	90
2	Cuban Pine	410	10,600	2,800	9,500	6,500	7,900	61	93
3	Shortleaf Pine	330	8,500	4,500	7,600	4,800	5,900	47	90
4	Loblolly Pine	660	11,200	3,900	8,700	5,400	6,500	49	84
	Reduced to 12 per cent moisture.								
5	White Pine	130	8,500	3,200	6,800	4,000	5,400	49	93
6	Red Pine	100	8,200	4,300	8,100	4,900	6,700	54	96
7	Spruce Pine	170	10,000	4,400	8,800	5,600	7,300	66	95
8	Bald Cypress	655	9,900	2,900	8,500	4,200	6,000	31	74
9	White Cedar	87	6,200	3,200	6,000	4,400	5,200	79	99
10	Douglas Spruce *a*	41	8,900	4,100	8,100	4,200	5,700	28	65
11	White Oak	218	12,500	5,100	11,300	6,300	8,500	40	81
12	Overcup Oak	216	9,100	3,700	8,600	6,000	7,300	70	95
13	Post Oak	49	8,200	5,900	8,100	6,000	7,100	58	100
14	Cow Oak	256	11,500	4,600	9,800	5,600	7,400	51	89
15	Red Oak	57	9,700	5,400	9,200	5,500	7,200	36	94
16	Texan Oak	117	11,300	5,800	9,800	6,900	8,100	62	98
17	Yellow Oak	40	8,600	5,500	8,300	5,800	7,300	58	100
18	Water Oak	31	9,200	6,200	9,000	6,300	7,800	75	100
19	Willow Oak	153	11,000	4,200	8,700	5,500	7,200	51	88
20	Spanish Oak	251	10,600	3,700	9,500	5,100	7,700	61	94
21	Shagbark Hickory	137	13,700	5,800	10,900	7,500	9,500	79	97
22	Mockernut Hickory	75	12,200	6,200	11,600	8,000	10,100	65	99
23	Water Hickory	14	10,000	6,700	9,600	7,000	8,400	71	100
24	Bitternut Hickory	25	11,500	7,300	11,200	7,800	9,600	60	100
25	Nutmeg Hickory	72	12,300	6,400	11,000	7,100	8,800	79	97
26	Pecan Hickory	37	10,500	5,800	10,400	7,300	9,100	51	95
27	Pignut Hickory	30	13,000	8,700	12,700	8,900	10,900	72	100
28	White Elm	18	8,800	4,900	8,800	5,000	6,500	28	88
29	Cedar Elm	44	10,600	6,200	10,100	6,500	8,000	66	95
30	White Ash	87	9,600	5,000	8,700	5,700	7,200	48	96
31	Green Ash	10	9,800	6,600	9,800	6,600	8,000	29	100
32	Sweet Gum	118	8,900	4,600	8,500	5,600	7,100	60	97

a Actual tests on "dry" material not reduced for moisture.

The variation in strength in wood of the virgin forest, as will be seen from the tables, is in some species so great that by proper inspection and selection values differing by 25 to 50 per cent

may be obtained from different parts of the same tree and values differing 100 to 200 per cent within the same species. These differences have all their definite recognizable causes, to find and formulate which is the final aim of these investigations.

The tests are intentionally *not* made on selected material (except to discard absolutely defective pieces), but on material as it comes from the trees, so as to arrive at an average statement for the species, when a sufficient number of trees has been tested. How urgent is the need for data of inspection as above indicated will appear from the wide range of results recorded.

To enable any engineer to use the data here given with due caution and judgment, not only the ranges of values and the average of all values obtained, but also the proportion of tests which came near the average values have been stated, as well as the average results of the highest and lowest values of 10 per cent of the tests. With this information and a statement of the actual number of tests involved, the comparative merit of the stated values can be judged. With a large number of tests, to be sure, it is more likely that an average value of the species has been found. The actual test results have been rounded off to even hundreds in the tables.

INFLUENCE OF MOISTURE.

One of the most troublesome factors influencing the strength of wood is the amount of moisture contained in it. As has been shown in Circular 12, this influence apparently produces in the Southern pines during the process of seasoning from green (over 33 per cent moisture) to dry (about 10 per cent moisture) condition variations of over 75 per cent in the average strength, the strength increasing with the decrease in moisture. Hence it is necessary in a statement of strength values to refer to the moisture condition of the material from which the value is derived. In the following tables all values except those for the Southern pines have been referred to 12 per cent moisture, which may be said to be the highest average moisture contents of seasoned wood; in addition, the majority of the tests were made on sticks of about that moisture, so that a fair average could be established. Since, however, the determination of the exact moisture contents and of their distribution through the stick (which must also have an influence especially in bending tests when only the extreme fibers are tested) is exceedingly difficult, and hence not absolute in results, and since in addition it was impracticable to take account of the specific gravity, which exercises also an important influence on strength, the values can be considered only as the best approximations attainable, still requiring for practical use the application of proper factors of safety. For the Southern pines it seemed best to give the values for a 15 per cent moisture, as published heretofore, until the law of variation according to which the reductions may be made has been more carefully investigated.

Provisionally the following approximate factors of correction are given:

Values to be added to strength factors of Southern pines at 15 per cent moisture in order to reduce them to 12 per cent.

Species.	Crushing endwise.	Bending—		Modulus of elasticity.	Crushing across grain.
		At elastic limit.	At rupture.		
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Longleaf Pine (*Pinus palustris*)	1,100	1,500	1,700	180,000	180
Cuban Pine (*Pinus heterophylla*)	800	1,500	1,700	70,000	220
Loblolly Pine (*Pinus tæda*)	900	1,000	1,200	100,000	150
Shortleaf Pine (*Pinus echinata*)	600	600	900	80,000	60

In this connection it may be of interest to state that when moisture contents are above a certain limit, say 33 per cent, and evenly distributed, i. e., in green timber, no varying influence is observable with varying moisture (the addition of water filling then the cell lumina, and hence not further swelling the cell walls). In future it may be desirable to test only green or saturated timber for lowest safe standard values, eliminating the moisture influence and avoiding the difficult moisture determinations.

FACTORS OF SAFETY.

With such lowest standard values, also lowest factors of safety could be employed. As to factors of safety, it may be proper to state that the final aims of the present investigations may be summed up in one proposition, namely, to establish *rational factors of safety.* It will be admitted

by all engineers that the factors of safety as used at present can hardly be claimed to be more than guesswork. There is not an engineer who could give account as to the basis upon which *numerically* the factors of safety for wood have been established as "8 for steady stress; 10 for varying stress; 15 for shocks" (see Merriman's Testbook on the Mechanics of Materials); or as 4 to 5 for "dead" load and 5 to 10 for "live" load (see Rankine's Handbook of Civil Engineering).

The directions for using these indeterminate factors of safety given in the text-books would imply that the student or engineer is, after all, to rely on his judgment as to the modification of the factor, i. e., he is to add to this general guess his own particular guess. The factor of safety is in the main an expression of ignorance or lack of confidence in the reliability of values of strength, upon which the designing proceeds, together with an absence of data upon which to inspect the material. With a larger number of well-conducted tests, coupled with a knowledge of the quantitative as well as qualitative influences of various factors upon strength, and with definite data of inspection which allow ready sorting of material, the factor of safety, as far as it denotes the residuum of ignorance which may be assumed to remain, as to the character and behavior of the material, may be reduced to a minimum, restricting itself mainly to the consideration of the indeterminable variation in the actual and legitimate application of load.

TABLE III.—*Results of tests in compression endwise on green wood (above 40 per cent moisture, not reduced).*

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average of all tests.
1	Longleaf Pine	86	7,300	2,800	4,300
2	Cuban Pine	38	6,100	3,500	4,800
3	Shortleaf Pine	8	4,000	3,000	3,300
4	Loblolly Pine	69	5,500	2,600	4,100
7	Spruce Pine	71	4,700	2,800	3,900
8	Bald Cypress	280	8,200	1,800	4,200
9	White Cedar	34	3,400	2,300	2,900
11	White Oak	25	7,000	3,200	5,300
12	Overcup Oak	45	4,900	2,800	3,800
14	Cow Oak	58	4,900	2,300	3,800
16	Texan Oak	39	6,000	3,100	5,200
19	Willow Oak	49	5,500	2,300	3,800
20	Spanish Oak	52	5,100	2,500	3,900
21	Shagbark Hickory	22	6,900	3,500	5,700
22	Mockernut Hickory	18	7,200	4,500	6,100
23	Water Hickory	4	5,600	4,700	5,200
25	Nutmeg Hickory	26	5,500	3,700	4,500
26	Pecan Hickory	4	3,800	3,300	3,600
27	Pignut Hickory	5	6,200	4,700	5,400
32	Sweet Gum	6	3,600	3,000	3,300

While the values given in these tables may claim to contain more elements of reliability than most of those published hitherto, much more work will have to be done before the above-stated aim will be satisfied.

In explanation of Table V, it should be stated that since an elastic limit in the sense in which the term is used for metals, namely, as a point at which distortion becomes disproportionate to load and a permanent injury and set results, can not be readily determined for wood, Prof. J. B. Johnson has proposed to utilize a point where the rate of distortion becomes 50 per cent greater for the amount of load than it was for the initial load, which point can be tolerably accurately determined (see Bull. 8, p. 9). This point he has called the "relative elastic limit." The assumption is that such a point would be near the limit to which the material can be strained without permanent injury, and the strength values obtained at that point would serve for indications of safe loads.

The practical utility of determining this point and the strength values relating to it remains, however, still open for discussion. A comparison of the values obtained for the strength at rupture and at relative elastic limit shows a parallelism which would make it questionable whether much is gained by the use of that point, which in reality lies beyond the limit where practical injury has begun, as indicated by the increased distortion.

We would be inclined to consider that point more serviceable where the curve begins to deviate from the straight line, at which point we may assume no permanent injury has as yet been experienced. This point we may call provisionally the "safe limit."

Objection has been made to utilizing this point because it can not be located with as much nicety and mathematical precision as the point of "relative elastic limit." But even this point is only approximately definable; and since no strength values can claim to be more than approximately correct, it would suffice to determine the safe-limit point and the correspondent strength values also only approximately. This point has the advantage that it lies on the safe side.

Special series of tests to investigate the legitimacy of the use of any of these limits for practical purposes were designed, but have as yet not been taken up, and hence the values in Table V (p. 10) are given only as suggestions for what they are worth.

TABLE IV.—*Results of tests in bending, at rupture.*

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average highest 10 per cent of tests.	Average lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*
1	Longleaf Pine	1,160	17,800	3,300	14,200	8,800	10,900	41	84
2	Cuban Pine	390	17,000	2,900	14,600	8,800	11,900	46	83
3	Shortleaf Pine	330	15,300	5,000	12,400	7,000	9,200	40	79
4	Loblolly Pine	650	14,800	3,900	13,100	8,100	10,100	44	84
	Reduced to 12 per cent moisture.								
5	White Pine	120	11,100	4,600	10,100	5,000	7,900	43	81
6	Red Pine	95	12,900	3,100	12,300	4,900	9,100	28	60
7	Spruce Pine	170	16,300	3,100	13,600	5,800	10,000	43	81
8	Bald Cypress	655	14,800	2,300	11,700	5,000	7,900	25	69
9	White Cedar	87	9,100	3,500	8,400	4,000	6,300	32	78
10	Douglas Spruce *a*	41	13,000	3,800	12,000	4,100	7,900	22	58
11	White Oak	218	20,300	5,700	18,500	7,600	13,100	39	75
12	Overcup Oak	216	19,600	4,900	14,900	6,300	11,300	47	81
13	Post Oak	49	16,400	5,100	15,300	7,400	12,300	47	92
14	Cow Oak	256	23,000	3,300	12,500	6,500	11,500	32	68
15	Red Oak	57	16,500	5,700	15,400	9,100	11,400	46	84
16	Texan Oak	117	19,500	8,200	16,900	10,000	13,100	64	86
17	Yellow Oak	40	15,000	5,100	14,600	5,700	10,800	28	65
18	Water Oak	31	16,000	5,800	15,700	7,200	12,400	40	76
19	Willow Oak	153	16,000	3,200	13,800	5,400	10,400	33	70
20	Spanish Oak	257	17,300	5,000	15,600	6,900	12,000	40	72
21	Shagbark Hickory	187	23,300	5,700	20,300	9,400	16,000	46	84
22	Mockernut Hickory	75	20,700	5,300	19,700	7,900	15,200	45	78
23	Water Hickory	14	18,000	5,300	17,300	5,400	12,500	21	64
24	Bitternut Hickory	25	19,500	7,000	19,300	8,700	15,000	28	60
25	Nutmeg Hickory	72	16,600	6,700	15,600	8,100	12,500	40	88
26	Pecan Hickory	37	18,300	5,600	18,100	10,300	15,300	38	95
27	Pignut Hickory	30	25,000	11,100	24,300	11,500	18,700	43	77
28	White Elm	18	14,000	7,300	13,600	7,300	10,300	44	72
29	Cedar Elm	44	19,200	6,600	17,300	8,500	13,500	50	86
30	White Ash	87	15,000	5,000	14,200	6,300	10,800	37	77
31	Green Ash	10	16,000	5,100	16,000	5,100	11,600	20	60
32	Sweet Gum	118	14,400	5,100	12,700	6,000	9,500	39	79

a Actual tests on "dry" material not reduced for moisture.

RELATIONS OF WEIGHT AND STRENGTH.

That within the same species the strength of wood varied with the dry weight (specific gravity), i. e., that the heavier stick is the stronger, has been known for some time. That this law of variation held good not only for a given species but irrespective of species for the four principal pines of our Southern States was indicated in Circular 12 of this Division. This fact becomes the more important in practical application, as the wood of these species of pines so far can not be distinguished at all by its anatomical structure and only with difficulty and uncertainty by other appearances, while in the lumber market substitution is not infrequent. It will therefore be best

with these pines, where strength alone is desired, to inspect the material by weight (specific), other things being equal, disregarding species determination.

While this result of the exhaustive series of tests reasonably well demonstrated for these pines may be considered of great practical value, we can now extend the application of the law of relation between weight and strength a step farther, and state as an indication of our tests that probably *in woods of uniform structure strength increases with specific weight*, independently of species and genus distinction, i. e., *other things being equal, the heavier wood is the stronger*. We are at present inclined to state this important result with caution, only as a probability or indication, until either the test material and tests can be more closely scanned, or more carefully planned and minutely executed series of detail tests can be carried on to confirm the truth of what the wholesale tests seem to have developed.

In the following two diagrams the average strength of the different species in compression endwise and bending, as found in the preceding tables, has been plotted with reference to the dry weight as given in Table 1.

Considering that these tests and weight determinations (especially the latter) were not carried on with that finesse which would be required for a scientific demonstration of a natural law, that other influences, as crossgrain, unknown defects, and moisture conditions may cloud the results, and that in the averaging of results undue consideration may have been given to weaker or stronger, heavier or lighter material, the relation is exhibited even by this wholesale method with a remarkable degree of uniformity bordering on demonstration.

An exception is apparent in the oaks in that they do not exhibit this relation of weight and strength with reference to other species, and also with less definiteness among the various species of oak in themselves. The structure of oak wood being exceedingly complicated and essentially different from that of the wood of all other species under consideration, it may reasonably be expected that it will not range itself with these.

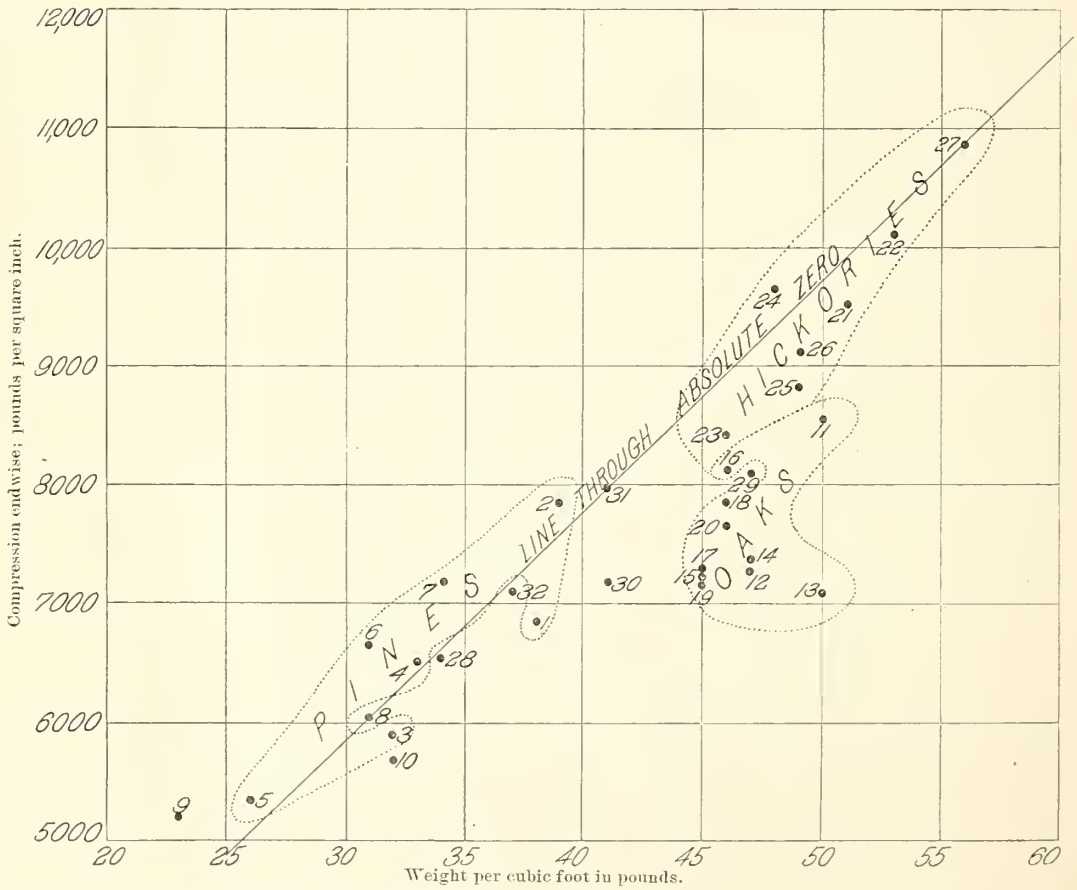

DIAGRAM 1.—Relation of strength in compression endwise to weight of material. The figure at each point indicates the species thereby represented.

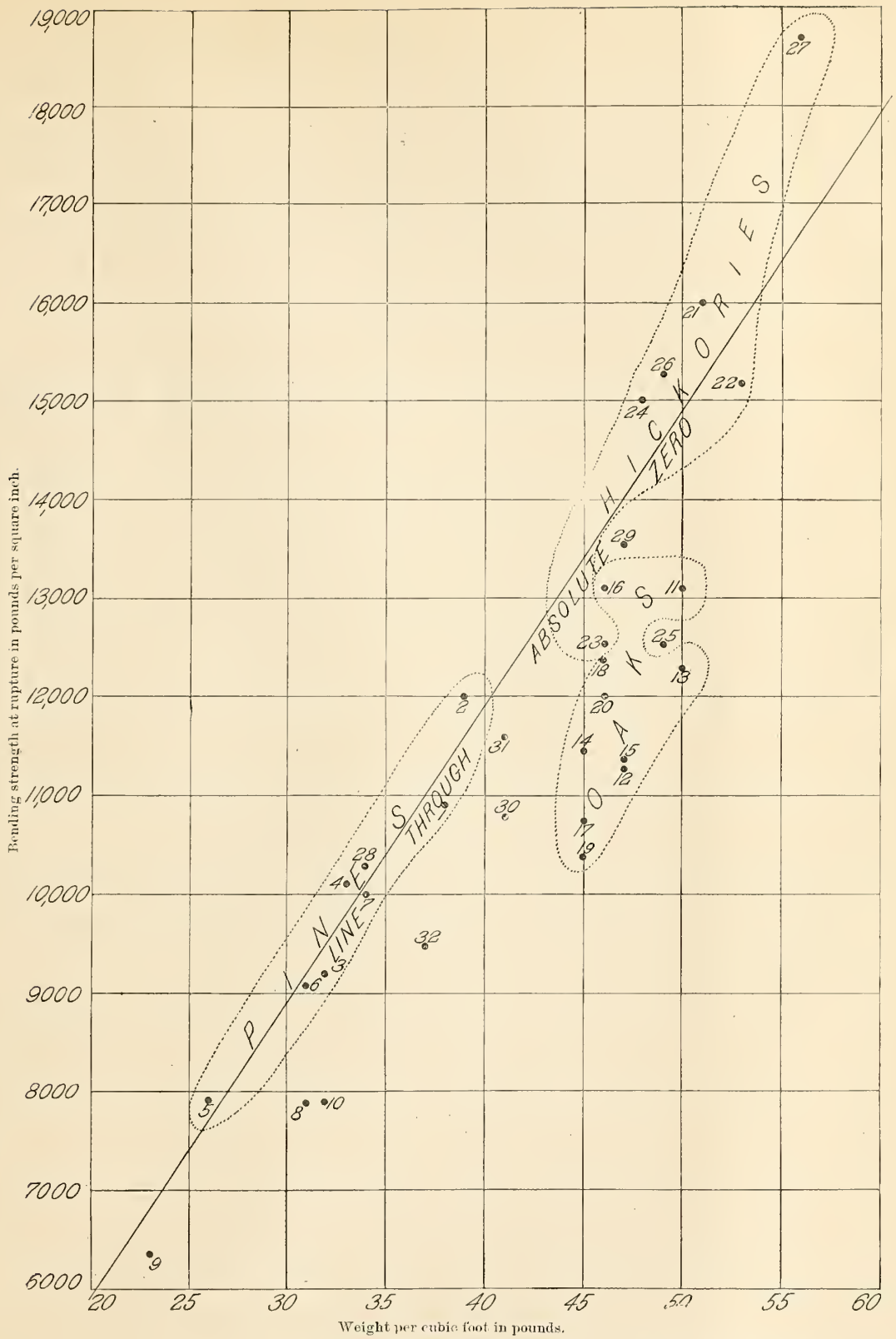

DIAGRAM 2.—Relation of weight to bending strength at rupture. The figure at each point indicates the species thereby represented.

In addition, the difficulty of seasoning oak without defects or even securing perfect material may have influenced the results of tests so as to cloud the relationship within the genus.

If further close study, supplemented by additional series of tests carefully devised to investigate this relationship, should uphold the truth of it, this result may be set down as the most important practical one that could be reached by these tests, for it would at once give into the hands of the wood consumer a means of determining the relative value of his material as to strength and all allied properties by a simple process of weighing the dry material; of course with due regard to the other disturbing factors like crossgrain, defects, coarseness of grain, etc.

It was thought best to announce this result before further examination in order to exhibit the real object, importance, and practical value of these investigations, and thus secure their continuance.

TABLE V.—*Results of tests in bending, at relative elastic limit.*

[Pounds per square inch.]

No.	Species.	Number of tests.	Highest single test.	Lowest single test.	Average of highest 10 per cent of tests.	Average of lowest 10 per cent of tests.	Average of all tests.	Proportion of tests within 10 per cent of average.	Proportion of tests within 25 per cent of average.	Modulus of elasticity (average of all tests).
	Reduced to 15 per cent moisture.							*Per cent.*	*Per cent.*	
1	Longleaf Pine	1,160	13,500	2,400	11,100	5,400	8,500	43	81	1,890,000
2	Cuban Pine	390	12,900	2,200	11,500	5,600	9,500	42	83	2,300,000
3	Shortleaf Pine	330	11,900	2,900	9,700	4,800	7,200	48	81	1,600,000
4	Loblolly Pine	650	12,700	3,100	10,800	5,400	8,200	46	85	1,950,000
	Reduced to 12 per cent moisture.									
5	White Pine	130	10,000	4,100	8,200	4,500	6,400	58	85	1,390,000
6	Red Pine	95	11,300	3,100	10,300	4,500	7,700	38	73	1,620,000
7	Spruce Pine	170	13,700	3,000	11,200	5,000	8,400	51	82	1,640,000
8	Bald Cypress	655	12,000	2,200	9,900	4,200	6,600	25	66	1,290,000
9	White Cedar	87	8,200	3,400	7,390	4,000	5,800	44	86	910,000
10	Douglas Spruce[a]	41	13,700	2,800	9,600	3,400	6,400	32	56	1,680,000
11	White Oak	218	15,700	4,400	14,100	6,100	9,600	37	73	2,090,000
12	Overcup Oak	216	11,600	4,000	9,500	5,400	7,500	47	91	1,620,000
13	Post Oak	49	10,600	5,100	9,600	6,000	8,400	34	76	2,030,000
14	Cow Oak	256	14,200	3,400	11,600	5,000	7,600	50	95	1,610,000
15	Red Oak	57	14,500	5,100	13,600	5,600	9,200	15	49	1,970,000
16	Texan Oak	117	12,000	5,900	11,400	7,800	9,400	62	94	1,860,000
17	Yellow Oak	40	11,800	4,900	11,100	5,100	8,100	35	75	1,740,000
18	Water Oak	31	11,800	4,500	11,400	5,500	8,800	40	84	2,000,000
19	Willow Oak	153	13,100	2,700	10,000	4,300	7,400	42	81	1,750,000
20	Spanish Oak	257	13,500	5,100	11,600	6,600	8,600	41	80	1,930,000
21	Shagbark Hickory	187	16,100	5,400	14,200	7,700	11,200	50	89	2,390,000
22	Mockernut Hickory	75	15,400	4,300	14,600	7,800	11,700	39	83	2,320,000
23	Water Hickory	14	11,900	4,100	11,800	4,800	9,800	21	86	2,080,000
24	Bitternut Hickory	25	14,300	7,500	14,000	7,600	11,100	44	84	2,280,000
25	Nutmeg Hickory	72	12,200	4,200	11,200	6,400	9,300	46	93	1,940,000
26	Pecan Hickory	37	15,000	5,800	14,400	7,900	11,500	65	89	2,530,000
27	Pignut Hickory	30	17,500	7,400	16,400	8,300	12,600	40	83	2,730,000
28	White Elm	18	9,700	5,300	9,600	5,400	7,300	33	71	1,540,000
29	Cedar Elm	44	10,700	4,700	10,100	5,800	8,000	57	91	1,700,000
30	White Ash	87	11,500	3,600	10,400	5,200	7,900	43	83	1,640,000
31	Green Ash	10	13,200	3,200	13,200	3,200	8,900	40	70	2,050,000
32	Sweet Gum	118	11,000	3,500	10,100	5,100	7,800	46	82	1,700,000

[a] Actual tests on "dry" material not reduced for moisture.

At the present writing all work in timber testing has been abandoned. If authority is given to resume it would be expected to divide the work into two distinct series, namely, one the object of which would simply be to ascertain by a large number of tests, similar to those hitherto performed, the average strength values of our important timbers, amplifying the data on some of those already taken in hand and extending the work especially to Pacific Coast timbers; the other to ascertain by specially devised and carefully performed tests and examination of test material the conditions and laws upon which strength values in wood depend, the physical properties of

the woods and their dependence on anatomical structure, and the behavior of wood in general, with a view of furnishing data of inspection.

There were also planned investigations into such practical questions, having reference to the technology of wood, as the following: Principles and proper methods of seasoning in dry kilns (a bulletin on this subject is in manuscript awaiting only a series of check tests and amplification in the direction of practical questions); depth of penetration of various antiseptics and their comparative value in preserving timber; relative inflammability and combustibility of different woods; comparative value of fire retardents and limits of their useful application, etc.

TABLE VI.—*Results of tests in compression across grain (a) and shearing with grain.*

[Pounds per square inch.]

No.	Species.	Number of tests.	Compression across grain.	Shearing with grain not reduced for moisture.	No.	Species.	Number of tests.	Compression across grain.	Shearing with grain not reduced for moisture.
	Reduced to 15 per cent moisture.					*Reduced to 12 per cent moisture—* Continued.			
1	Longleaf Pine	1,210	1,000	700	16	Southern Red Oak	117	2,000	900
2	Cuban Pine	400	1,000	700	17	Black Oak	40	1,800	1,100
3	Shortleaf Pine	330	900	700	18	Water Oak	30	2,000	1,100
4	Loblolly Pine	690	1,000	700	19	Willow Oak	153	1,600	900
	Reduced to 12 per cent moisture.				20	Spanish Oak	255	1,800	900
					21	Shagbark Hickory	135	2,700	1,100
5	White Pine	130	700	400	22	White Hickory	75	3,100	1,100
6	Red Pine	100	1,000	500	23	Water Hickory	14	2,400	1,000
7	Spruce Pine	175	1,200	800	24	Bitternut Hickory	25	2,200	1,000
8	Bald Cypress	650	800	500	25	Nutmeg Hickory	72	2,700	1,100
9	White Cedar	87	700	400	26	Pecan Hickory	37	2,800	1,200
10	Douglas Spruce *b*	41	800	500	27	Pignut Hickory	30	3,200	1,200
11	White Oak	218	2,200	1,000	28	White Elm	18	1,200	800
12	Overcup Oak	216	1,900	1,000	29	Cedar Elm	44	2,100	1,300
13	Post Oak	49	3,000	1,100	30	White Ash	87	1,900	1,100
14	Cow Oak	256	1,900	900	31	Green Ash	10	1,700	1,000
15	Red Oak	57	2,300	1,100	32	Sweet Gum	118	1,400	800

a To an indentation of 3 per cent of the height of the specimen.
b Actual tests on "dry" material not reduced for moisture.

The laborious compilations of the test data, which have served as a basis for the above statements, have been performed by Mr. S. T. Neely, C. E., under the supervision of Prof. J. B. Johnson, who has also superintended the tests under instructions from this office.

B. E. FERNOW,
Chief Division of Forestry.

Approved:
J. STERLING MORTON,
Secretary.

The publications of the Division of Forestry so far issued as a result of the timber physics work are:

Bulletin 6. Timber Physics, Part I, a preliminary statement of the scope and history of timber physics and of the methods pursued in these investigations. 4°, 57 pp. Price 10 cents.

Bulletin 8. Timber Physics, Part II, being an exhaustive report of the results with Longleaf Pine. 4°, 92 pp. This bulletin is out of print.

Bulletin 10. Timber, being a brief discussion of the characteristics and properties of wood in general, with a key and list to the commercial woods of the United States. 1895. 8°, 88 pp. Price 10 cents.

Bulletin 12. Economical Designing of Timber Trestle Bridges, being an application of some of the results to practical problems. 8°, 57 pp. This bulletin is out of print.

Circulars 8 and 9 announcing results of the tests on bled and unbled Longleaf Pine.

Circular 12. Southern Pines, Mechanical and Physical Properties, giving a résumé of the results of 20,000 tests and of an exhaustive physical examination of the four species under consideration. 4°, 12 pp.

Other publications still on hand for gratuitous distribution or obtainable by purchase are:

Annual Report for 1891, containing chapters on poisoning of street trees, bamboo a substitute for wood, and discussion of Southern lumber pines.

Annual Report for 1892, 8°, 65 pp., containing statement regarding forest conditions and the forestry movement in the United States, and a chapter on the Naval Store Industry.

Annual Report for 1893, 8°, 60 pp., containing statement regarding consumption and supply of forest products and an account of German forestry methods.

Extract from Yearbook, 1894: Forestry for Farmers. 8°, 39 pp.

Extract from Yearbook, 1895: Relation of Forest to Farms, and Treeplanting in the Western Plains. 8°, 27 pp.

Bulletin 11. Some Foreign Trees for the Southern States. 8°, 32 pp.

Bulletin 13. The Timber Pines of the Southern United States. A fully illustrated monograph. 4°, 160 pp. Price 35 cents.

Bulletin 14. Nomenclature of the Arborescent Flora, giving scientific and vernacular names and synonyms of 492 species of our trees. 8°, 419 pp. Price 25 cents.

Circular 3. Increasing the Durability of Timber, brief statement of causes and prevention of decay. 8°, 4 pp.

Circular 5. Arbor day planting in Eastern States, giving instructions how to plant single trees. 4°, 4 pp.

Circular 6. Instructions for growing Tree seedlings. 4°, 4 pp.

Circular 10. Suggestions to Lumbermen in behalf of rational forest management.

Circular 11. Facts and Figures; brief statements regarding consumption and supplies of forest resources. 8°, 8 pp.

Circular 13. Forest Fire Legislation in the United States, giving résumé or reference to the laws in existence. 8°, 8 pp.

Circular 14. Is Protection against Forest Fires practicable? 4°, 4 pp.

These Bulletins and Circulars can be had at the prices noted by application to the Superintendent of Documents, Government Printing Office, Washington, D. C., payment to be made by coin or postal note.

Where no prices are noted, a limited number of copies for free distribution is still on hand.

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